II. ARTERIOTOMY FOR THROMBOSIS AND EMBOLISM.

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THE usual treatment for arterial obstruction involving the limbs and depending upon thrombosis or embolism, is in brief to keep the part dry, warm, sterile, and slightly elevated, in order to prevent gangrene, or at least limit it and cause it to assume a dry and circumscribed form. With the development of aseptic surgery and the progress which has been made in the suture of arteries more active measures demand at least consideration. These measures will vary according to the cause of the arterial obstruction, since the problems to be solved differ with the lesion encountered. We shall confine ourselves to the two forms which we have an opportunity to investigate by operation.

1. *Traumatic thrombosis* due to contusion of an artery.—By contusion we mean an injury produced by blunt violence which does not result in immediate dissolution of the continuity of the external coat of the vessel, in other words, such injuries as are often described as partial ruptures. The lesions found after a contusion of an artery vary with the violence of the contusion and the state of the arterial walls. The slightest grade, in which there is perhaps no change but a little ecchymosis of the vessel wall, may be disregarded, as such causes neither immediate signs nor remote ill effects. The older surgeons explained some of the cases of obliteration of an artery after contusion, by rupture of the vasa vasorum, and extravation of blood between the vessel and its sheath in sufficient quantity to press upon and considerably narrow the lumen of the vessel. This was supposed to be followed by a traumatic arteritis with consequent thrombosis. It is now known that in practically all instances the inner coats of the vessels rupture and that such leads to thrombosis. As in the application of

a ligature, although the force acts from without inwards, the lesions, owing to the friability of the internal coats are produced from within outwards. The injury may expend itself on the internal coat alone, leaving the outer coats intact and practically normal. The lesion here observed is a fissuring of the intima, which may be complete or incomplete, *i.e.*, involving the entire circumference or only a part thereof. Complete circular division is best seen after the application of a ligature. In contusions by blunt violence the fissures are apt to be multiple, and frequently involve only a portion of the circumference of the vessel, usually that first struck. The sole result of clinical importance is thrombosis with its consequences. If the fissure is small and incomplete, there may be a minute mural thrombus, which causes no interference with the blood current, but simply protects the wound until healing is complete. Obliteration of the vessel by clot is liable to follow, however, if the rent in the internal coat is large, if the fissures are multiple, if the tunic is sufficiently detached to wave in the blood stream, if the detached tunic is infiltrated with lime salts, if tight compression is applied after the accident, or if the state of the heart or the blood is such as to predispose to coagulation. The conditions just mentioned determine also the rapidity with which an occluding thrombus forms. It may immediately follow the injury or it may not develop for several hours or even days. Generally speaking, complete obliteration after a lesion of the internal coat alone is delayed, although in the femoral artery we have observed it to occur within a few minutes. Yielding of the internal and middle coats is much more likely to be followed by immediate thrombosis, since they curl up within the vessel in obedience to the elasticity of the middle coat. The adventitia maintains the continuity of the vessel and prevents extravasation, although the blood may make its way for some distance between this coat and the media, sometimes for an inch or more. Ordinarily the clot extends centrally in a conical form as far as the first collateral branch. Peripherally its length varies; it may fill the main branch and the smaller arteries or it may terminate like the central portion near a collateral. Upon its extent and upon the activity of the collateral circulation depends the integrity of the limb. If the injury is confined to the artery alone, and the vessels are healthy and the collaterals abundant, no harm need follow. If the clot forms slowly, ample opportunity is afforded for the development of an adequate collateral circulation, which becomes progressively more efficient the more the lumen is closed; thus pulsation may never be absent from the peripheral vessels, even though the vessel at the contused point becomes impervious. If, however, the vessels are narrowed by disease, or if the collaterals are involved in the injury or pressed by extravasated blood or a tight bandage, the collateral circulation will be insufficient and the thrombosis may extend to the finer vessels. In either event the limb falls into gangrene. Another possible factor in the production of gangrene is the detachment of portions of the clot during the formation of the thrombus, the emboli plugging the smaller vessels and leading to circumscribed gangrene. In the absence of sepsis secondary hemorrhage does not occur.

The signs of obliteration of the vessel (pain, pallor, loss of pulsation, loss of heat, hypesthesia of anesthesia, paresis or paralysis) when marked are followed by gangrene, but when present in a lesser degree complete recovery is still possible. Such, however, is the exception and the limb usually perishes for several reasons. Unlike simple ligation, after which gangrene is comparatively rare, in a contusion the accompanying vein also may be involved and thrombosed. The collateral vessels too are apt to suffer from the trauma, or if they escape direct injury they may be compressed by the extravasated blood resulting from the associated laceration of the environing tissues. Of 34 cases of traumatic thrombosis collected by Lears 18 recovered, and of these only 4 escaped gangrene.

If the pulse alone has disappeared and there are no other signs of impending gangrene, the treatment mentioned at the beginning is all that is needed. A hematoma, however, should always be opened, in order to lessen the compression on the collateral vessels. If the hematoma is of large size, one can never be sure that the artery has not been opened, hence in these cases incision has a double rôle, to permit evacuation of the blood and to ascertain the condition of the artery. The clots adhere strongly to and infiltrate the surrounding tissues, but the tissues should not be scrubbed in order to remove them. If the bleeding has completely ceased we believe it good practice to suture the wound without drainage, since the latter always predisposes to infection, particularly in bruised tissues.

On theoretical grounds ligation of the artery above the injured part has been suggested in order to prevent the detachment of emboli. If the pulse has disappeared, indicating complete obliteration of the vessel, no reason exists for this procedure; if the pulse is still present, although of lessened force and volume, we believe the chances of embolism should be accepted rather than completely to suppress the circulation. Although the possibility of opening the artery, removing the thrombus, then suturing the wound in the vessel has probably occurred to many surgeons we imagined at the time of our first operation that we were the first to put the idea into practice. On looking over the literature, however, we find that both Sabanajew and Lejars have attempted to relieve arterial obstruction by arteriotomy.

Sabanajew's operation was performed in 1896 (Höpfner, Archiv f. klin. Chir. Bd. 70, S. 417, 1903). His patient, suffering with polyarthritis rheumatica, was suddenly stricken with signs of gangrene of the leg depending upon obstruction of the femoral artery, which was believed to be due to an embolus. The femoral artery was exposed, but no occlusion found in the expected situation. Owing to the desperate condition of the patient, further search was deemed inadvisable, and the vessel was closed with sutures and the limb amputated at a lower level. The patient died 19 days later of endocarditis.

Lejars' (Bull. et mem. de lo soc. de chir. de Paris, 1902, p. 609), patient was a man, aged 26 years, who was caught between two cars, sustaining a severe contusion of the left inguinal region. Signs of thrombosis of the femoral artery were in evidence, and the foot became gangrenous. Six days after the accident the artery was exposed below Poupart's ligament, a soft black clot removed, and the wound in the vessel closed with sutures. The gangrene progressed, however, and one month later the leg was amputated below the knee.

For our first case we are indebted to Dr. Robert G. Le Conte, who was absent from the city when the patient was admitted to the Pennsylvania Hospital, June 20, 1905. The patient was a man, aged 60 years, who presented all the evidences of advanced atheroma, with mitral regurgitation and hypertrophy of the heart. He had been squeezed between the tail-board of a wagon and a wall. Over the lower portion of the left abdomen and upper part of the corresponding thigh was a diffuse swelling due to extravasated blood. The skin was unbroken and there were no other injuries. Both legs were bluish and covered with a network of small varicose veins. Pulsation in the tibial vessels was as strong and full on the left as on the right side. During the night of the same day, or about twelve hours after the injury, he complained of severe pain, first in the popliteal space, and later radiating down the leg to the foot and toes. The following morning we found the pulse absent from the tibial vessels and popliteal artery. The femoral could not be satisfactorily palpated because of the swelling mentioned above. The pain had disappeared, but the leg as far as the knee was pale and cold, and the toes and foot shriveled. Sensation was present but markedly reduced in the entire foot and leg. There was no power in the toes, and the ankle could be flexed only with difficulty. Movements of the knee were unimpaired. The thigh was warm and apparently in the same condition as on admission. Owing to the condition of the thigh, the very sudden onset of symptoms, and the seat of the initial pain, it was believed that a large clot embolus had been swept from the point of injury and lodged at the bifurcation of the popliteal. About 12 hours after the onset of pain and 24 hours after the injury the patient was anesthetized with ether, and the popliteal artery opened by a small longitudinal incision. There was a slight flow of dark blood, but no clot could be found. A probe was gently passed up into the artery for about 6 inches and no obstruction found nor flow of blood induced. The wound in the artery was closed with through-and-through silk sutures and the skin approximated. A longitudinal incision was next made over the femoral artery, from just above Poupart's ligament downwards. The sartorius muscle had been ruptured and all the tissues were infiltrated with dark clots. The vein was uninjured. The artery was not discolored, but was hard to the touch from Poupart's ligament down to its bifurcation.

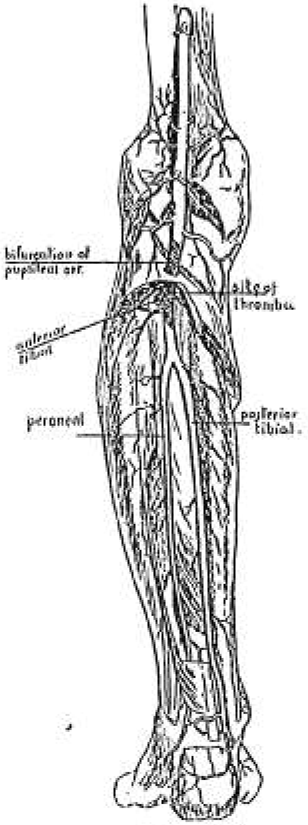
Poupart's ligament was severed in order to permit an assistant to grasp the vessel above the thrombus, and the artery was opened by a longitudinal incision.

After removing the clot, which was almost black in color and firmly adherent, it was discovered that, like a valve, a calcified portion of the intima had been turned into the artery from the anterior wall, probably occluding it one-half. The posterior wall of the artery, although calcareous in places, was apparently uninjured. The detached atheromatous plate was removed, and the compression on the artery diminished for an instant in order to wash out any remaining debris. The artery was then closed with through-and-through silk sutures. The circulation was immediately reëstablished, but after the lapse of a brief period pulsation below the injured point ceased. The arterial stitches were then removed and the vessel again found filled with clot. This was removed and the artery resutured. The same phenomena were repeated, and the hopelessness of securing a patent lumen by simple removal of the thrombus realized. The injured portion of the artery was therefore excised by a diamond-shaped incision, with the idea of closing the wound transversely. This, however, was found to be impossible, so that the artery was completely severed and each end split on the posterior wall, the flaps thus formed being turned outwards and the segments of the artery united with through-and-through silk sutures, bringing intima in contact with intima. Although the circulation was again reëstablished, at the time the skin wound was sutured pulsation in the artery below the site of anastomosis had become very feeble and no pulse could be felt in the tibial vessels. The gangrene, which was of the moist septic type, progressed rapidly and the limb was amputated through the upper thigh 10 days later by Dr. Le Conte. The flaps subsequently sloughed and reamputation was performed about one month later by Dr. Hutchinson. The patient finally recovered.

The chief difficulty in an operation like the foregoing is to prevent the reformation of the thrombus. The clot intimately adheres to the internal tunic and can be completely removed only with some difficulty, thereby subjecting the delicate lining membrane of the artery to further injury. If the artery is simply opened, the clot removed, and the vessel sutured, the cause of the thrombosis, *i.e.*, the multiple cracks in the intima or the curling up of the internal coat, is not suppressed, and the thrombus will quickly reform as it did in our case. There are several ways in which this may possibly be prevented. If the contusion is sufficiently limited, the injured portion of the artery may be resected, and the vessel anastomosed by Carrel's technic. The advantages of this method over Murphy's anastomosis by invagination are quite obvious, as the latter considerably diminishes the lumen of the vessel and does not permit the removal of as much artery as the former. The extent of vessel which may be excised without exerting too much tension on the sutures will vary somewhat with the situation; thus in resection near joints flexion may be utilized to diminish tension, while in other regions, particularly where the artery is bound to the surrounding parts by branches, it will be impossible to effect anastomosis after the removal of a large extent of vessel. In the latter instance severances of the collaterals would probably facilitate this manœuvre, but generally would be contraindicated. Kümmel was able to approximate the ends of a femoral artery after resecting two inches, during an operation for cancer of the inguinal region. Another method of restoring the circulation after traumatic thrombosis which at once suggests itself is to substitute a segment of a vein for the injured portion of the artery, a procedure which has already been employed in the treatment of aneurysm. Whether or not the operation is feasible cannot be definitely stated at the present time. Experimentally varying results have been obtained. Höpfner transplanted a segment of a vein to an artery in 10 animals. The vein at once became twice the size of the artery. The twirling of blood within it could be seen and, as in aneurysm, this led to thrombosis. Efforts were made to prevent the dilatation of the vein by doubling it, *i.e.*, by turning one end back like a cuff, and also by suturing the surrounding tissues over it. The ultimate results were negative, as secondary hemorrhage occurred in one and thrombosis in all the others. The success obtained by Carrel in the transplantation of vessels in animals is well known and need not be recited here. Whether or not the companion vein should be employed for this purpose would depend upon the artery involved. One would not think of transplanting a segment of the popliteal or the femoral vein to its accompanying artery, as in case of failure both the arterial and venous circulations would be suppressed and the chances of gangrene very great. Probably the best vein to substitute would be the external jugular, although one of the brachial veins or even the opposite femoral vein might be employed. If the saphenous vein is sufficiently large, it likewise might be transplanted. In the arm where there are two venæ comites one of these could be selected.

Embolism.—The difficulty mentioned above would not be encountered in dealing with an embolus soon after its lodgment, indeed the chances of thrombosis would be no greater than after the most favorable form of arteriorrhapy, since the intima is likely to be smooth at the point of impaction of the embolus. Case two we submit as one of embolism, although we have no means of definitely excluding primary thrombosis. As an impacted embolus quickly becomes the nucleus of a thrombus, the exact diagnosis from the standpoint of arteriotomy is unimportant. The important thing is the condition of the intima.

The patient was a man, aged 61 years, who had never been seriously ill before. He was suddenly attacked with generalized abdominal pain, vomiting, and constipation. This persisted for two days, at which time we saw him with his physician, Dr. James M. Montgomery, who feared the case might be one of intestinal obstruction. There was no fever, the pulse was about 100, and the intrathoracic organs normal. The abdomen was flat, soft, and slightly tender in the region of the left kidney. Rectal examination was negative. The blood vessels were distinctly atheromatous. With the use of laxatives and enemas the bowels were finally induced to move, and the abdominal symptoms subsided. In the meantime the patient developed a cystitis with bloody urine, possibly as the result of the catheterization which was found necessary at the beginning of the illness. About five days after the abdominal pain subsided the patient experienced a sudden excruciating pain in the right foot, which rapidly extended to the lower third of the thigh, and was accompanied by pallor, loss of heat, loss of tactile sensation, inability to move the limb, and coldness. We saw him the following day and found the limb cold as far as the middle of the thigh. The foot was



Showing thrombus in popliteal artery.

shriveled, and the leg purplish as far as the upper third. Pulsation could not be felt in any of the vessels below the bifurcation of the femoral. Thirty-six hours after the onset of pain the patient was sent to the Jefferson Hospital, and the common femoral artery exposed by a longitudinal incision. It pulsated vigorously to within one inch of the bifurcation. From this point to the bifurcation it was hard, and below the bifurcation collapsed. The vessel was isolated, compressed, and opened by a longitudinal incision about one inch long. The thrombus was Y-shaped, corresponding to bifurcation, the base of the Y being about one inch long and tapering at the tip. The limb corresponding to the superficial femoral was ½ inch long and also tapering at the tip. The limb corresponding to the deep femoral was one inch long and likewise tapering. The color of the thrombus was dirty white, with bright red spots and black blotches, except the terminal ½ inch of the limb corresponding to the deep femoral, which was jet black. The intima was smooth, although the vessel wall was decidedly thickened. On removal of the thrombus blood flowed freely from the peripheral part of the deep femoral, but not from the peripheral part of the superficial. The vessel was closed with a continuous through-and-through suture of silk, and over this a second layer uniting the outer coats only. Pulsation immediately reappeared in the femoral below and in the popliteal, but not in the tibial vessels. The skin wound was closed without drainage. After operation pulsation continued in the popliteal about one-half the strength for three days, then began to grow weaker, finally disappearing on the eighth day. In the meantime a large vessel on either side of the patella (superior external articular, anastomotica magna) pulsated more vigorously as the pulsation in the popliteal became weaker. The pain in the leg continued, being particularly marked in the popliteal space. The line of demarcation which formed was an irregular oval, the inside reaching to the junction of the lower with the middle third of the leg, and the outside to the junction of the upper and middle third. In the deeper structures the gangrene ascended to a higher level. Forty-two days after the first operation the leg was amputated below the tubercle of the tibia, lateral flaps of equal length being employed. About 15 ligatures were necessary, and the bone bled freely on section. The popliteal artery contained a small clot, and a probe passed up into the artery for several inches caused a slight flow of blood.

Perhaps the first thought which strikes one after reading the above cases is the inability which was encountered in two instances to locate definitely the obstruction by the mere symptoms. In our first case we feel sure that the mistake would not have occurred could we have palpated the femoral artery itself. It seems that the symptoms are caused, not by the thrombus itself or by even the sudden impaction of an embolus, but by the result of the arterial obliteration, *i.e.,* the acute anemia, thus the pain, etc., are referred to the area from which the blood is excluded, and not to the seat of obstruction. It will be seen, however, that the operation of thrombectomy or embolectomy, if it may be so called, can be readily performed without danger of secondary hemorrhage. We believe it to be indicated particularly when the intima is smooth, and that to be of value it must be performed as soon as possible after the arterial obstruction develops. Even though the vessel again becomes obstructed with clot, as in our second case, this may form slowly and give the collateral vessels a chance to dilate, thus saving at least a portion of the limb.